Control processes in visual spatial attention

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7 Summary and Conclusions

7.1 Introduction

In recent years the there has been growing interest in the topic of attentional control in the field of cognitive neuroscience. The first chapter of this thesis introduces the relevant theoretical concepts in the study of selective attention and gives an overview of what has become known from studies of brain activity about the mechanisms that are involved spatial selective attention and in shifting attention from one location to another. Much has been learned from spatial cueing studies, in which a central cue indicated the relevant location for an upcoming target stimulus. Electrophysiological and hemodynamic measures recorded in the interval following the onset of such a cue have shown that frontal and parietal brain areas are active during shifts of spatial attention. These activities are considered to reflect successive stages in the control of visuospatial attention that lead to modulated excitability in the extrastriate visual areas. This 'selective state' of secondary visual cortex might be related to the effects of sensory gain that are observed in the ERPs elicited by stimuli presented at the location at which attention was focused. Hemodynamic studies also showed frontal and parietal brain areas to be activated when spatial attention was shifted.

The general aim of the research in this thesis was to use multichannel ERPs to gain more insight into mechanisms of attentional control. The research questions that are addressed are: 1) are the same attentional control processes that are involved in selecting a peripheral location involved when attended and unattended information are presented at the same location, but differ in the amount of detail that is processed? 2) Is spatial selection involved when colour determines which stimulus is relevant? 3) What is the role of oculomotor preparation processes in the control of spatial attention? 4) In what way are the cue-induced ERP lateralisations effected by the particular cue stimulus that is presented? 5) What are the temporal dynamics of shifts of spatial attention in touch?

7.2 Attention Shifts between the Global and the Local Level of a Hierarchically Organised Stimulus

In the study presented in Chapter Two the spatial cueing paradigm was adapted to instruct subjects to attend to either the global or the local level of a hierarchically organized stimulus. The main objective of this study was to test if the interpretation of the cueing effects observed with cueing a peripheral location can be extrapolated to other selective attention paradigms. If the late cueing effect (LDAP) reflects the modulation of excitability in those brain areas that are specialized in processing the relevant location or the relevant stimulus attributes, we would expect to see an asymmetrical ERP cueing effect in the present study, with preparation effects being larger over the right hemisphere for global-cue trials and larger over the left hemisphere for local-cue trials. However, the results showed that the ERPs elicited by the global and local cue stimuli were symmetrical. We concluded that instead of preparing the hemisphere that is specialised to deal with the information at the attended level, preparation effects may reflect the sizing of the attentional window to the appropriate size, i.e. smaller for local information and larger when global information is relevant. The time course and topography of the effects of cueing on the ERPs elicited by the presentation of the compound stimulus confirm the involvement of a spatial attention mechanism.

More evidence for a role for spatial attention mechanisms in the processing of compound stimuli comes from the trials in which the symbol at the attended level indicated that attention had to be shifted to the other level (switch-trials). In these switch-trials, in which a switch was made from the focussed level to the information at the formerly unattended letter an interesting result was obtained. The topographical maps of the switch effects revealed that a parietal effect was observed when a switch was made from local to global, whereas a shift from global to local was accompanied by a more occipitally distributed effect. These effects suggest that a refocusing of spatial attention takes place when the attentional window needs to be broadened to access the formerly unattended global information.

7.3 The Role of Location Selection in a Colour Selection Task

Chapter Three presents a study that tests a central tenet of the location-special theories of selective attention, namely that spatial selection is involved even if information is selected on the basis of some other non-spatial stimulus property. ERPs were registered in a paradigm in which one blue and one red letter were presented simultaneously in a bilateral arrangement. The position of the blue and the red letter (left or right from fixation) was varied randomly. Subjects were instructed to detect infrequent target letters in one colour only and ignore the letters in the other colour. Although strictly speaking, the location of the letter stimulus is irrelevant for successful performance in this task, the location-special theories predict the selection of the stimulus in the relevant colour nevertheless must occur via the selection of its location in the location domain.

The results showed that selecting the relevant letter resulted in modulation of the P1 component. The scalp topography of this effect was similar to the distribution of the effect that has previously been observed when the location of a stimulus was the property that determined its relevance. These results are consistent with a special role for location information in visual selective attention, as stated by the location-special theories of attention.

Furthermore this study showed that the N2pc effect that is observed in multi-item stimulus arrays reflects processes involved in target discrimination, rather than the suppression of irrelevant information, as has previously been suggested.

7.4 Control Processes in Spatial Attention and the link with Eye Movement Preparation

The primary purpose of the experiment described in Chapter Four was to gain more insight into the role of motor preparation processes in shifting visuospatial attention. The Premotor theory states that shifting spatial attention to a peripheral location is equivalent to preparing to make a saccade to that location. Other theories also predict that motor preparation processes and attention are closely linked but do not specifically implicate the oculomotor system in attentional control.

A second research question was if the lateralised effects observed in previous cueing studies could be replicated if an arbitrary, symmetrical stimulus was used to direct attention.

In the experiment that is presented in this chapter subjects shifted attention to one of two peripheral locations (left and right) in response to a central colour cue. In one condition they responded to infrequent target stimuli presented at the attended location by making a manual response (button press) whereas in the other condition they made a saccade to the location of the relevant target. When we compared the lateralised preparation effects in the ERPs elicited by the cue stimulus in both conditions an early frontal effect was observed that differed in polarity. Also, the anterior lateralisation (ADAN) that has been reported in previous ERP studies of spatial cueing had an earlier onset when an eye movement was being prepared. The type of response that was prepared had no influence on the effects of spatial attention on the peripheral stimulus.

We conclude that the predictions made by the Premotor Theory appear to be too strong. We observed different lateralised cueing effects dependent on the effector system involved in the response. On the other hand, we also observed important similarities in the preparation effects and the effects of spatial attention in the ERPs elicited by the peripheral stimuli in both conditions. These similarities may be indicative of the strong links that do exist between processes involved in attentional control and motor preparations. This view is supported by the fact that the distribution of the ERP effects observed in the present study suggests the same brain areas are involved in shifting attention and in preparing to make a saccade.

With respect to our second research question we found that the early posterior lateralisation (EDAN) that was observed in previous studies that presented arrow cues to direct attention to a peripheral location was absent when symmetrical colour cues were used. We conclude that this effect probably reflects the processing of an asymmetrical cue stimulus and not a process involved in shifts of visual attention.

7.5 Cue-Related Lateralisations and the Role of Asymmetric Cue Stimuli

Chapter Five presents a further experiment into the role of the cue stimulus in eliciting lateralised ERP effects of spatial cueing. The absence of the early lateralised negativity (EDAN) in the study described in the previous chapter, in which colour cues were used to induce attention shifts suggest that this effect may be specific for asymmetrical cue stimuli, like arrow cues. To test this explanation we designed two types of asymmetrical cue stimuli, one that entailed the informative part on the same side as the destination location of the attention shift (as is the case with arrow stimuli) and one stimulus where the information was presented on the side opposite to the induced attention shift.

The results showed a posterior negativity is elicited contralateral to the informative side of the cue stimulus. This effect was similar to the N2pc effect that has previously been observed contralateral to the relevant element in a multi-stimulus array. This contralateral negativity appears to reflect the selection of the relevant side of an asymmetrical cue stimulus and not preparatory processes involved in shifting spatial to a peripheral location.

7.6 The Temporal Dynamics of Attention Shifts in Touch

In Chapter Six the cueing paradigm was applied to a tactile spatial attention paradigm. A visual cue indicated the hand to attend to, and subjects were instructed to detect infrequent targets presented to the relevant hand only. The interval between the onset of the attention-directing cue stimulus and the peripheral tactile stimulus was varied, to study the temporal dynamics of the ERP effects associated with attentional control. If the ADAN reflects attentional control processes in response to a cue stimulus, this effect should show a similar onset for all conditions. Because the LDAP is thought to reflect preparation of sensory areas in expectation of the upcoming stimulus it was expected that its onset would vary with the interval manipulation, so that preparation would be maximal at the expected time of the arrival of the tactile stimulus.

The results showed that the ADAN is time-locked to the onset of the cue stimulus, which is consistent with the interpretation of the ADAN in terms of cue-induced attentional control processes. Surprisingly, the onset of the LDAP effect did not differ between the conditions where the tactile stimulus appeared after short and longer intervals. These findings suggest that the LDAP is not a reflection of sustained anticipatory preparation for an upcoming peripheral event.

7.7 Directions for Future Research

The pattern of brain activity elicited by spatial cues in attention shifting paradigms consistently points to a role for a frontoparietal network in the control of visuospatial attention. Both ERP and hemodynamic studies suggest that activity in these areas leads to preparation of extrastriate areas in the anticipation of a target stimulus. It is however too early to assume a causal relation between these observed activations of frontal and parietal areas and the spatial attention effects observed in the ERPs elicited by the peripheral stimuli. In a first attempt to clarify the relation between ERP effects elicited by cue stimuli and the ERP reflections of selectively processing the peripheral target stimulus, Driver and colleagues (Driver, Eimer, Macaluso, & Van Velzen, 2004) report significant correlations between the amplitude of the early anterior lateralisation and the amplitude of the N1 spatial attention effect in the ERPs elicited by peripheral stimuli. In stimuli. In a similar way it may be possible to relate the magnitude of the changes in the hemodynamic response in response to cue stimuli to ERP effect on the one hand and to transient fMRI effects on the other hand. This would require ERPs and fMRI to be registered simultaneously, a method that is being developed at the moment. Ultimately it would be desirable to relate single-trial preparation effects with the resulting indices of selective processing.

Another promising approach to research into the mechanisms involved in spatial attention is the use of steady-state potentials of the brain. In these studies, the brain's synchronized response to continuously flickering visual stimuli can be used as an indicator of where the focus of spatial attention currently lies. Using this method it is possible to trace the trajectory of spatial attention and to assess in which way information is processed that is presented at locations in-between the (usually central) starting point and the goal location of an attention shift.